

Limitation of liquid crystal on silicon spatial light
modulator for holographic three-dimensional displays

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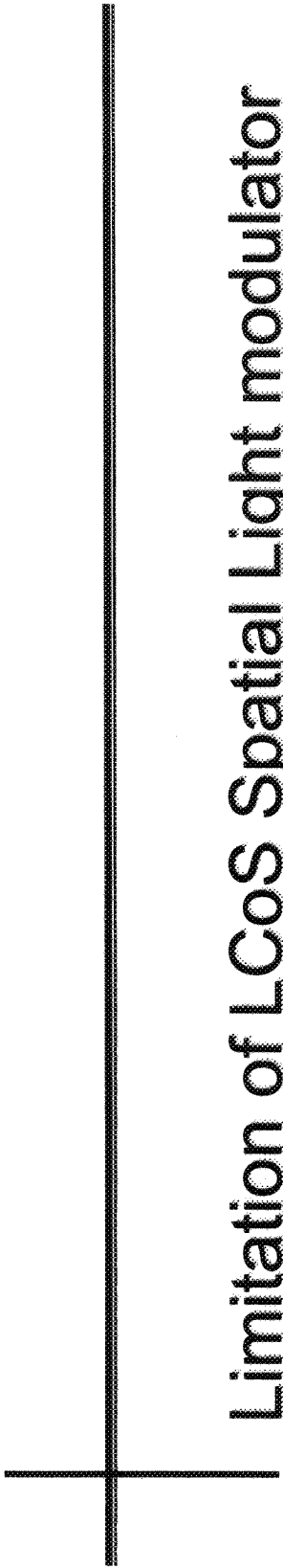
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Abstract

In a 3-D display system based on an opto-electronic reconstruction of a digitally recorded hologram, the field of view of such a system is limited by the spatial resolution of the liquid crystal on silicon (LCOS) spatial light modulator (SLM) used to perform the opto-electronic reconstruction. In this article, the spatial resolution limitation of LCOS SLM associated with the fringe field effect and interpixel coupling is determined by the liquid crystal director simulation and the Finite Difference Time Domain (FDTD) simulation. The diffraction efficiency loss associated with the imperfection in the phase profile is studied with an example of opto-electronic reconstruction of an amplitude object. A high spatial resolution LCOS SLM with a wide reconstruction angle is proposed.



Limitation of LCoS Spatial Light modulator (SLM) for holographic 3-D displays

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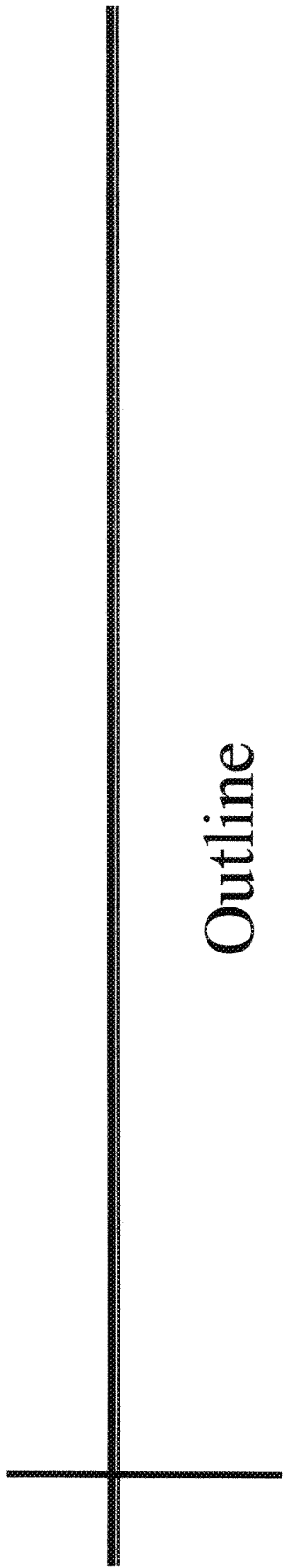
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Outline

- Introduction
- Spatial resolution limitation of LCoS
- Optimization
- Example of opto-electronic reconstruction

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The amount of information the human visual system can process is much larger than what can be offered by conventional display systems

-p. Hariharan

Conventional display	Stereoscopic displays	Holography
size	•binocular disparity	•The perception of depth
texture gradient		•binocular disparity
shading		•convergence and accommodation.
shadowing		
overlapping		
motion		
linear perspective		

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From film recorded hologram to electronic hologram

- Technical challenge

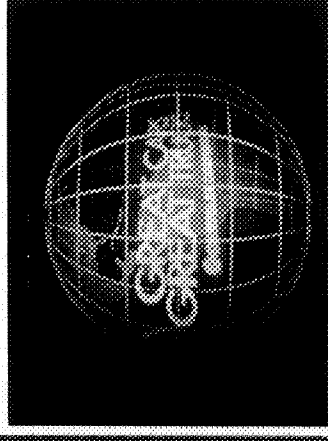
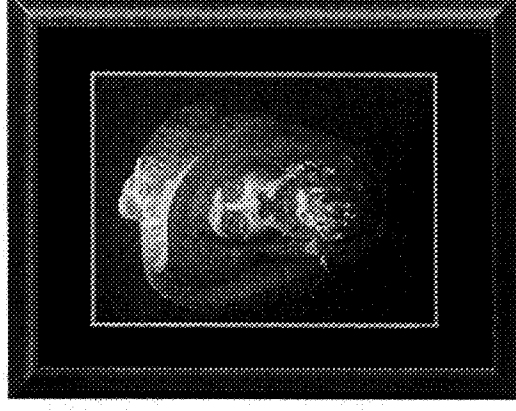
Spatial resolution of digital hologram

Diffraction efficiency

Field of view

High information content

Real time response



High resolution (1~3um pixel spacing) phase modulator

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Proposed 3D imaging and display system

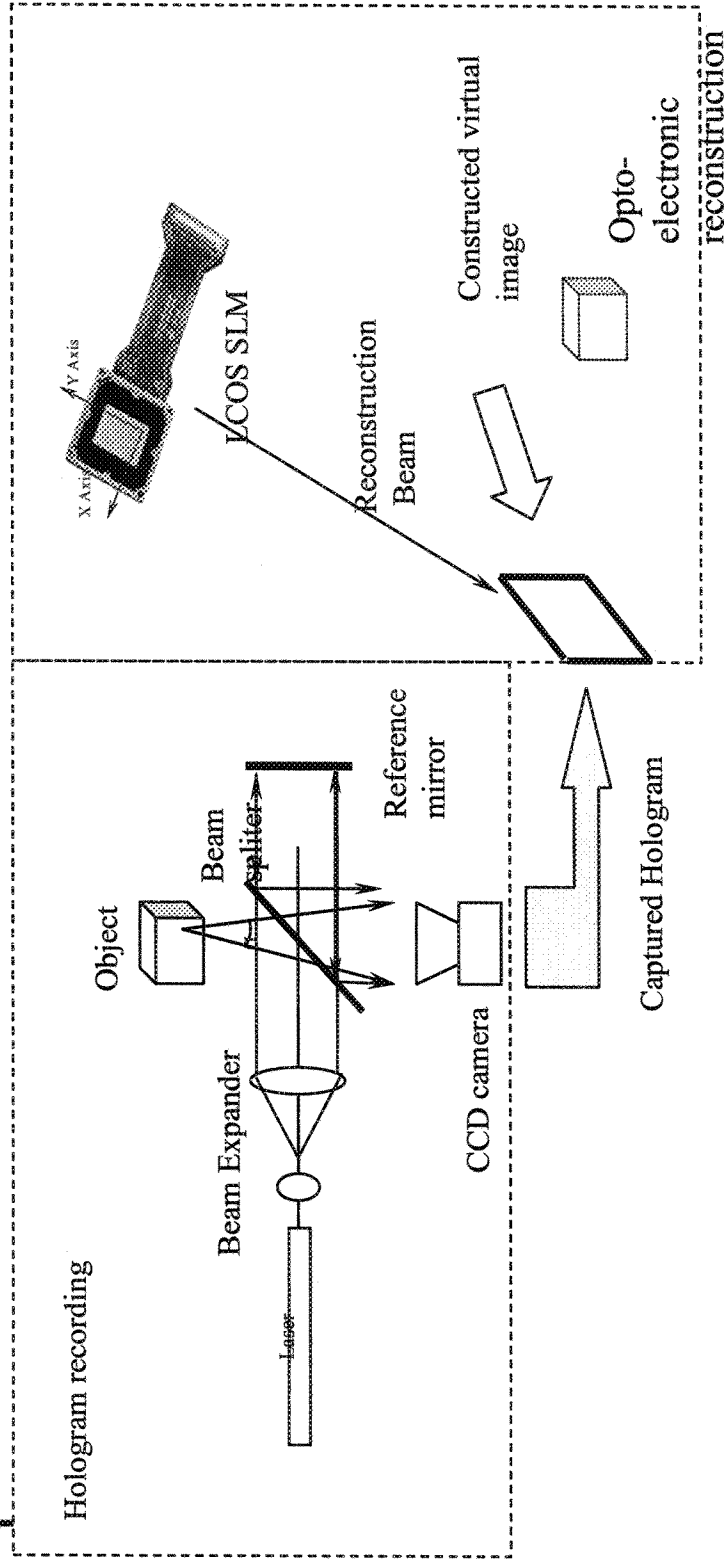
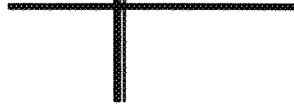


Figure: Digital holography recording and opto-electronic reconstruction system



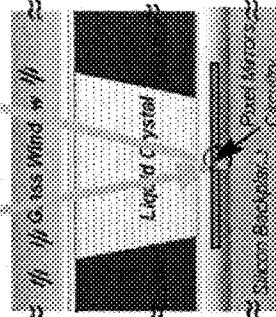
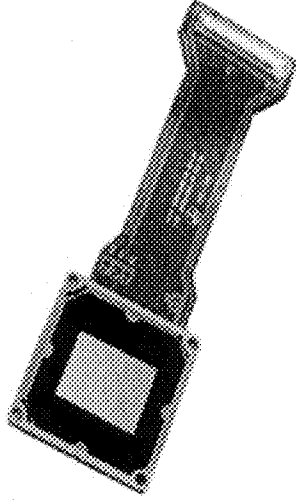
Liquid Crystal on Silicon Spatial light modulator



ISO 9002

**Light
IN**

Image OUT
(reflective devices)



**Liquid Crystal Display
(LCD)**

IC Backplane

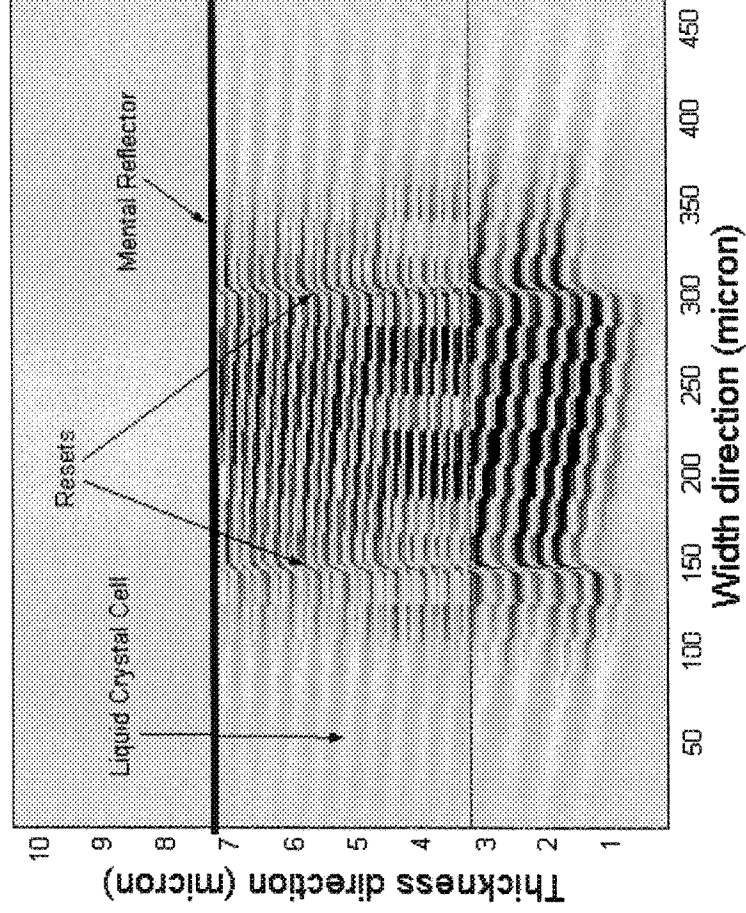
Resolution:	1024*768
Pixel Spacing:	19.4 μ m
Aperture:	20mm*15mm
Reflectivity:	80%
Filling factor:	96%
Speed:	50Hz, 25Hz, 5Hz
Effective stroke length:	0.7 μ m, 1.3 μ m, 2.5 μ m

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Light Propagation in LCoS

Finite Difference Time Domain simulation



simulated stair like blazed gratings formed by LC device

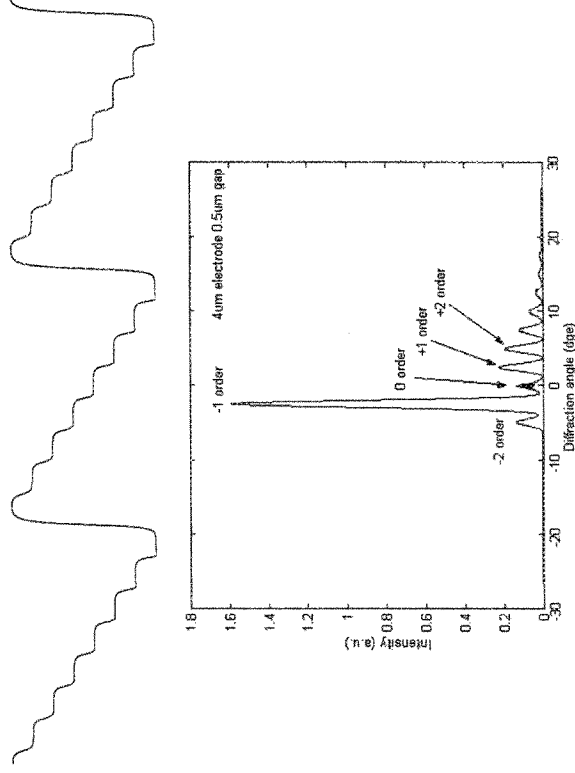


Figure: Simulated far field diffraction peak for 8 electrode/reset scheme with 4 μ m electrode and 0.5 μ m gap between electrode.

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Spatial resolution limitation of LC SLM

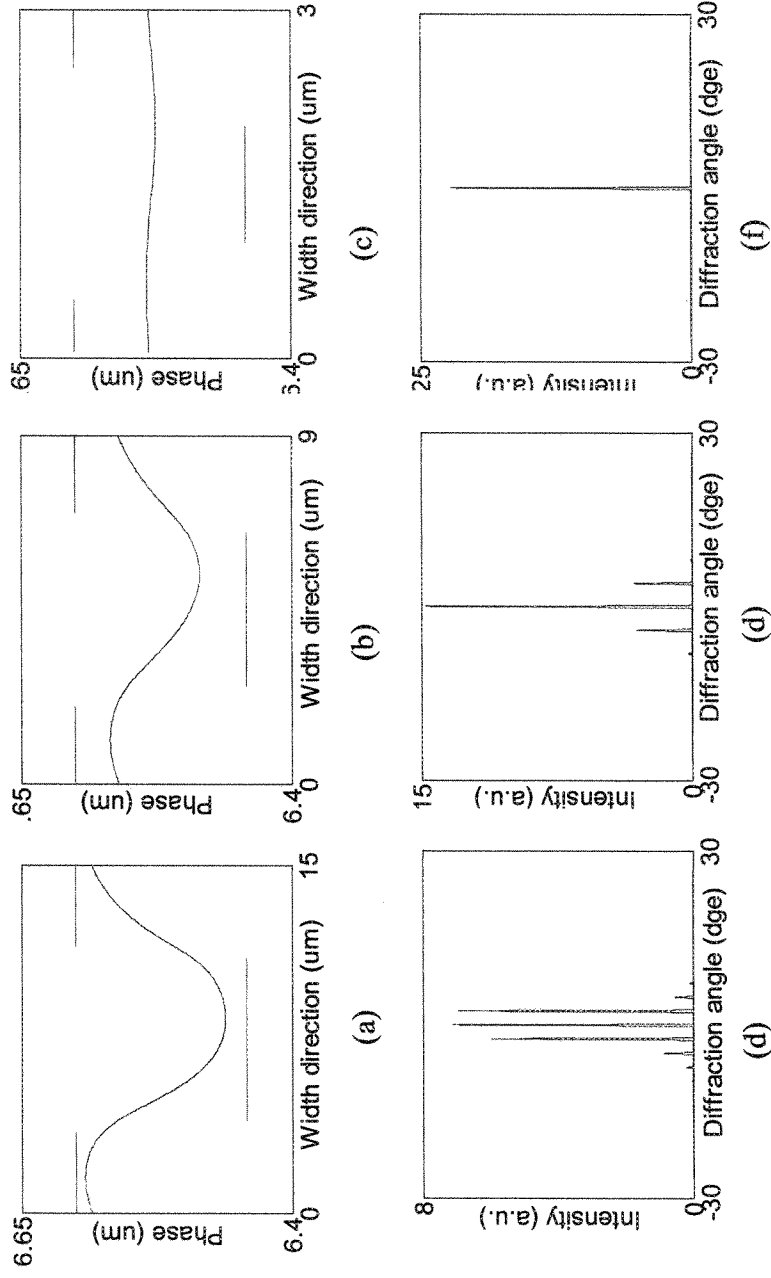


Figure: Near field phase profile and far field diffraction efficiency of LC binary grating, $\lambda = 632.8$ nm. (a) (d) $7.5 \mu\text{m}$ pixel spacing. (b)(e) $4.5 \mu\text{m}$ pixel spacing. (c) (f) $1.5 \mu\text{m}$ pixel spacing.

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Simulated performance of current LCoS

Diffraction angle β (deg)		0.94	1.73	2.42	4.02	7.21	12.1
$\lambda = 633 \text{ nm}$							
Pixel Spacing ($\mu \text{ m}$)		19.4	10.5	7.5	4.5	2.5	1.5
$\Delta n = 0.1707$	-1	35.1%	35.1%	31.7%	27.7%	2.1%	0.1%
$d = 4 \mu \text{ m}$	order						
	0	4.3%	4.3%	16.3%	31.9%	95.5%	99.6%
	order						
	+1	42.7%	42.7%	38.8%	32.2%	2.2%	0.1%
	order						

Reduce fringe field effect to achieve bigger field of view
and high diffraction efficiency

*Influence factor of diffraction efficiency of
LC OPA*

- Cell Thickness
- Δn value of LC material
- Pixel spacing
- Inter-pixel gap (Electrode geometry)
- Optical axis
- $\Delta n^*d/\lambda$ value
- Pretilt angle
- Elastic constant of LC material

Design	LC material	Δn	d (μm)	$\Delta n^*d/\lambda$ (double pass)
1	Hana fluid	0.1707	4.0	2.16
2	BL015	0.281	0.8	0.71
3	fictitious	0.35	0.6	0.66

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Improved design

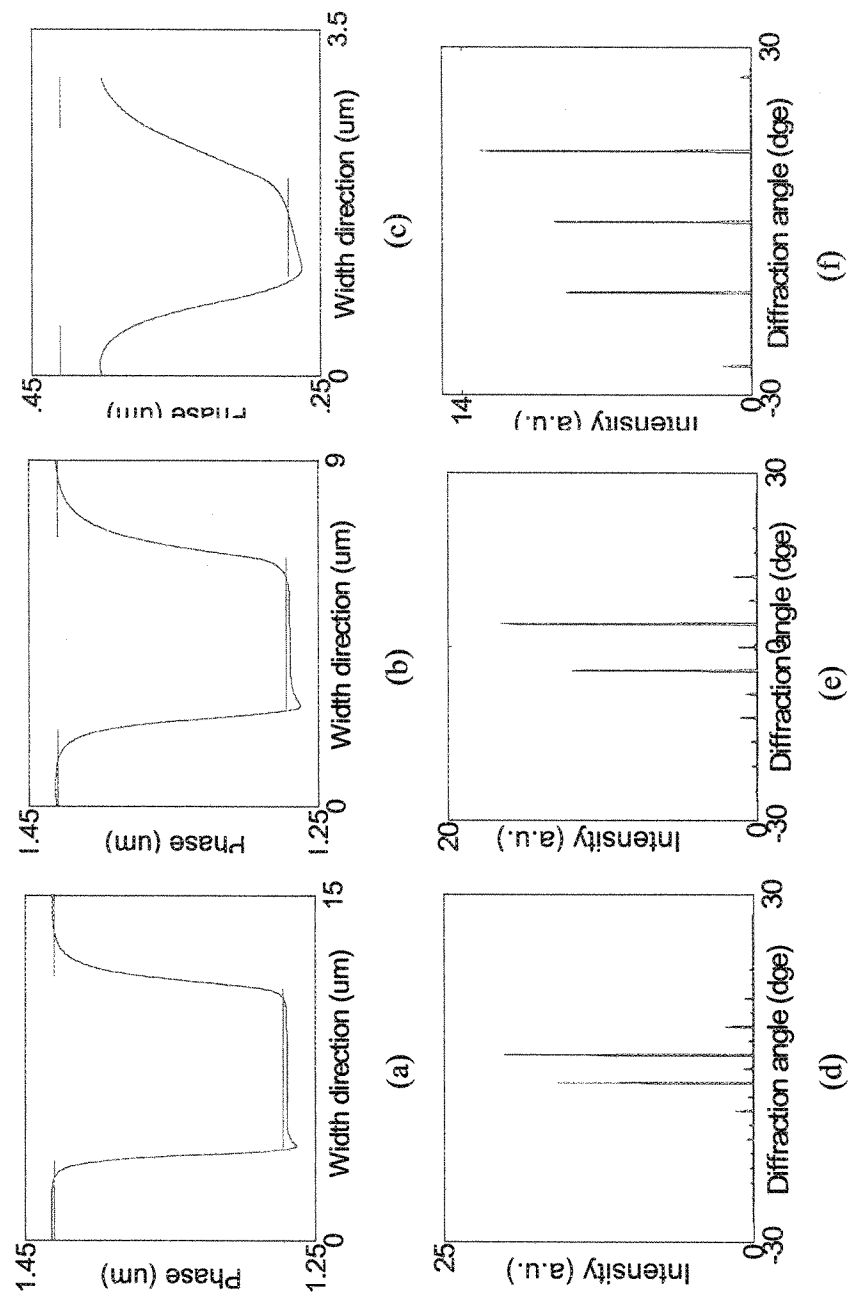


Figure: Far field diffraction efficiency of LC binary grating, BL015, $\Delta n=0.281$, cell thickness $d=0.8 \mu\text{m}$, $\lambda=632.8 \text{ nm}$. (a) $7.5 \mu\text{m}$ pixel spacing. (b) $4.5 \mu\text{m}$ pixel spacing. (c) $1.5 \mu\text{m}$ pixel spacing.

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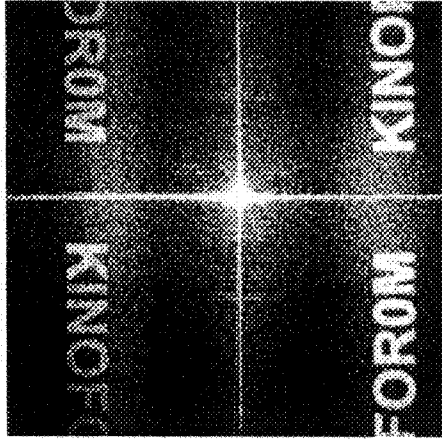
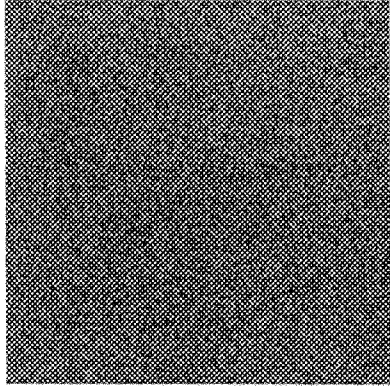
Limitation of spatial resolution of LCoS

Diffraction angle β (deg)		2.42	4.02	7.21	12.1
$\lambda = 633 \text{ nm}$					
Pixel Spacing (um)		7.5	4.5	2.5	1.5
$\Delta n = 0.281$ $d = 0.8 \text{ } \mu\text{m}$	-1 order	35.6%	33.7%	30.5%	26.9%
	0 order	1.7%	3.5%	12.2%	26.6%
	+1 order	46.5%	44.9%	42.7%	39.5%
$\Delta n = 0.35$ $d = 0.6 \text{ } \mu\text{m}$	-1 order	35.6%	33.7%	30.9%	27.1%
	0 order	1.7%	3.5%	8.3%	23.2%
	+1 order	50.8%	48.2%	46.2%	44.4%

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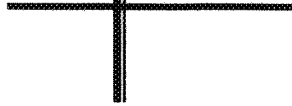
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Opto-electronic reconstructed amplitude object

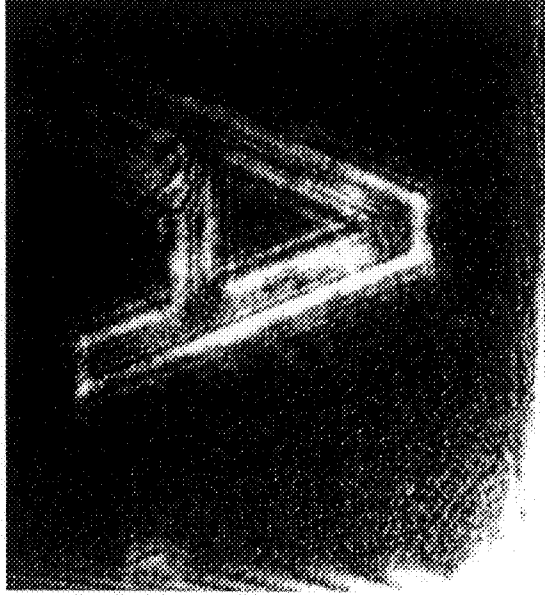
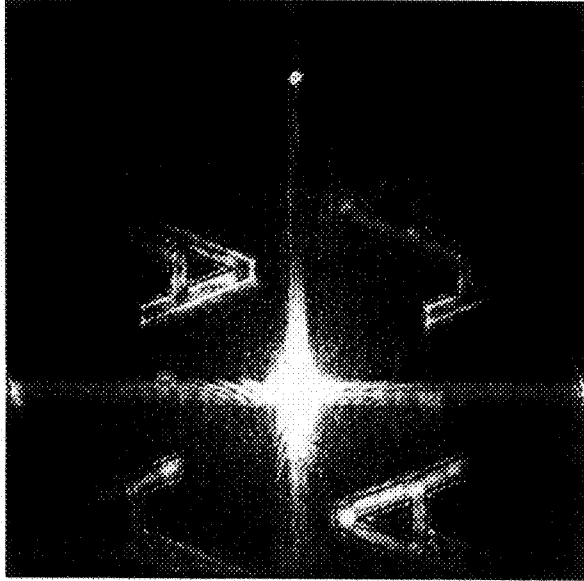


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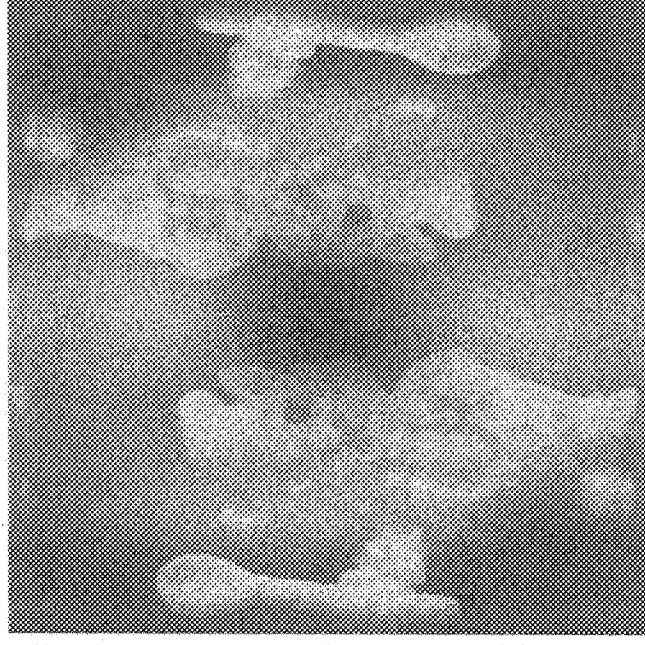
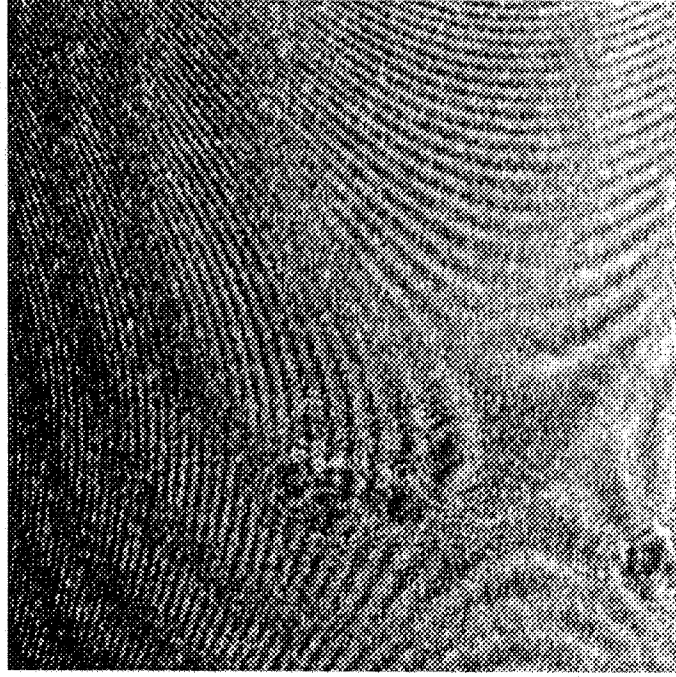
Reconstruction of amplitude object



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Digital reconstruction of phase objects



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